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Description**1. Field of the Invention**

The present invention relates to cement bond logging and more particularly to methods and apparatus
5 for measuring the attenuation rate of sonic energy traversing casing cemented in a borehole.

2. The Prior Art

In a well completion, a string of casing or pipe is set in a borehole and cement is forced into the annulus
10 between the casing and the borehole primarily to separate oil and gas producing formations from each other and from water bearing strata. Obviously, if the cementing fails to provide a separation of one zone from another, then fluids under pressure from one zone may be able to migrate and contaminate an otherwise productive nearby zone. Migration of water, in particular, produces undesirable water cutting of a producing zone and possibly can make a well non-commercial.

It is a problem to obtain an accurate picture of conditions behind a casing because of the difficulty of
15 propagating signals through the casing wall. Various prior proposals to determine the separation effectiveness, (i.e., the blocking or sealing characteristics) of the cement behind the casing have not been entirely successful in clearly determining the effective presence of cement in the annulus between the casing and the formation. Further, it has not been possible to measure reliably the quality of the cement bond between the casing and the cement.

The mere presence or absence of cement in the annulus between the casing and formation is valuable
20 information, however, this does not provide a complete picture of the cement conditions. While cement may be present in the annulus, channels or inadequate sealing many still permit fluid communication between adjacent formations.

Use of the term "bond" in connection with the relationship of cement to the casing or the formation is
25 somewhat vague, since adherence along the entire boundary between the casing and the cement or between the cement and formation is not necessary to prevent fluid communication between adjacent porous zones. All that is necessary of a bond is that the relationship prevents the migration of fluids. Hereafter, reference to bond will mean that separation of zones by cement is adequate to prevent fluid migration between the zones.

Several prior developments for obtaining a measure of the quality of a cement bond relative to the
30 casing have been disclosed e.g. in U.S. Patent Number 3,291,248. These systems generally utilize acoustic principles where an acoustic signal is transmitted between a transmitter and a receiver. The amplitude of the early arrival signal (this early arrival usually is the casing signal since the acoustic energy under average conditions generally travels faster in the casing than in the surrounding cement or formation) at
35 the receiver is measured as a determination of the quality of the bond of cement to the casing. If a good bond existed, the casing signal would be expected to be attenuated because of the energy dissipated from the casing to the cement and surrounding formations, whereas if no bond or a poor bond existed the casing signal would be relatively unattenuated.

A more refined technique for determining the quality of cement in the annulus between the casing and
40 the formations is disclosed in U.S. Patent No. 3,401,773 entitled, "Method and Apparatus for Cement Logging or Cased Boreholes" by Judson D. Synnott, III and assigned to the assignee of the present invention. In this technique the amplitude of a reverberated early (casing) signal arrival is recorded and additionally, the total energy of a selected later portion of the sonic signal is obtained by integration to provide a second indication of the quality of the cement bond. Even in the absence of a weak casing arrival,
45 the additional step of observing the total energy obtained by integrating a later portion of the signal in this manner can confirm the presence of cement in the casing-annulus-formation system. Details of related methods may also be had by reference to U.S. Patent No. 3,401,772 entitled, "Methods for Logging Cased Boreholes" by Frank P. Kokesh, which is assigned to the assignee of the present invention.

While the foregoing methods and apparatus provide very useful information, it is desirable to more
50 precisely determine the quality of the cement bond. It has been established that the energy content of the acoustic logging signals arriving at the receiver depends on other factors than the quality of the cement bond to the casing or the integrity of the cement column (sometimes called cement quality). The following factors were found to have substantial effect on signal arrivals: receiver sensitivity; the formation hardness; eccentricity of the acoustic logging tool; the high temperature environment and the temperature
55 variations in the well bore; type of casing; and the diameter of the borehole and casing as well as their shape or geometry.

It will be appreciated, therefore, that it is highly desirable to provide methods and apparatus for
determining the quality of the cement bond in a cased borehole, which methods and apparatus reduce the
detrimental effects of the aforementioned factors.

Summary of the Invention

It is a general object of the present invention to provide an improved method and apparatus for cement
bond logging a cased borehole.

This and other objects are attained, in accordance with one aspect of the invention, by a method
65 obtaining a measure of quality of a cement bond relative to a casing in a borehole comprising the steps of

establishing in a well tool having two longitudinally spaced acoustic transmitters and at least two longitudinally spaced acoustic receivers disposed between said acoustic transmitters with a transmitter receiver spacing to provide for a measurable signal-noise-ratio, the arrival of a casing signal prior to the arrival of a formation signal and to tolerate eccentricity of as much as 76 mm repetitively energizing said acoustic transmitters to apply acoustic energy into the casing surrounding said well tool; detecting at said receivers energy from a first of said transmitters arriving at said receivers by way of said casing; detecting at said receivers acoustic energy arriving by way of said casing from a second of said transmitters following the firing of said first transmitter; for each of the foregoing generations and detections measuring the peak amplitude of a selected portion of the acoustic casing signals detected at each of said receivers; obtaining a ratio of the peak amplitudes associated with the firing of said first transmitter; obtaining a ratio of the peak amplitude associated with the firing of said second transmitter; combining said ratios to produce a function representative of the attenuation of acoustic energy travelling through the casing; and recording said attenuation as a function of tool position in the borehole.

Another aspect includes apparatus for obtaining a measure of quality of a cement bond relative to a casing in a borehole comprising a well tool having two longitudinally spaced acoustic transmitters and at least two longitudinally spaced acoustic receivers disposed between said acoustic transmitters; said receivers being respectively spaced approximately 73 cm to 104 cm from each transmitter; means for repetitively energizing said acoustic transmitters to apply acoustic energy into casing surrounding said well tool; said receivers detecting energy from a first of said transmitters arriving at said receivers by way of said casing; said receivers detecting energy arriving by way of said casing from a second of said transmitters following the firing of said first transmitter; means for measuring the peak amplitude of a selected portion of the acoustic casing signals detected at each of said receivers; means for obtaining a ratio of the peak amplitudes associated with the firing of said first transmitter; means for obtaining a ratio of the peak amplitude associated with the firing of said second transmitter; means for combining said ratios to produce a function representative of the attenuation of acoustic energy travelling through the casing; and means for recording said attenuation rate as a function of tool position in the borehole.

A further aspect is attained by apparatus for determining the quality of the cement bond in a cased and cemented borehole traversing a fast formation comprising at least one transmitter for transmitting acoustic energy from the borehole into the casing and surrounding formation, at least one receiver spaced from said transmitter a distance of less than one foot for receiving a refracted portion of the transmitted energy to produce electrical signals representative thereof, means for producing a signal representative of the peak amplitude of the first halfcycle of received energy, and means for recording said peak amplitude as a function of depth.

The novel features of the present invention are set forth with particularity in the appended claims. The operation together with further objects and advantages of the invention may be best understood by way of illustration and examples of certain embodiments when taken in conjunction with the accompanying drawings.

Brief Description of the Drawings

Figure 1 illustrates an embodiment of a logging system using the principles of the present invention in block form;

Figure 2 is an enlarged view of a portion of Figure 1 indicating acoustic wave paths through the drilling fluid and the casing;

Figure 3 illustrates the form of acoustic signal travelling through a cemented casing under different cement bond conditions;

Figure 4 illustrates modification of a downhole sonde providing for minimum eccentricity under substantial well deviation conditions; and

Figure 5 illustrates a typical cement bond attenuation rate log produced in accordance with the present invention as well as other types of logs produced with the system of Figure 1.

Description of the Preferred Embodiment

In Figure 1 there is illustrated a logging system for carrying out the invention and including an elongated logging tool 10 provided with centralizers 11 for maintaining the tool centered as effectively as possible in a borehole 12. The borehole 12 is shown filled with fluid 13. The tool 10 is suspended in the well bore by means of cable 15 extending from the upper end of the tool to the surface of the earth. The cable 15, typically a mono-cable, is spooled on a winch, not shown, but as well known in the art the operation serves to raise and lower the tool 10 through the well bore 12. Indications of the depth at which the tool is suspended in the bore hole can be provided by means (not shown) for measuring the length of the cable. This information is utilized to provide one of the functions in the typical well log.

The tool 10 itself is divided into several sections. The lower section between the centralizers 11 includes a plurality of acoustic transducers including transmitters T1 and T2 as well as three acoustic receivers R1, R2 and R3. Above the acoustic transducers is a sonic cartridge containing the required electronics for processing data from the acoustic transducers as well as data from a collar detector 21 and a natural gamma ray detector 22. The upper part of the logging tool includes a telemetry modem 23 utilized to transmit information uphole as well as to act as a receiver of control information for the downhole equipment.

Operation of the logging system is under control of a properly programmed digital computer 30 located at the surface. The program or instructions for the computer are initially stored on tape transport 31 and upon command from terminal 32, are loaded into the computer 30. The terminal 32 includes a printer which provides a monitor for instructions from the terminal to the computer and also enables an operator to interrogate the computer. When the system is ready for operation the computer 30 will send a command to the downhole equipment via bus 33, telemetry modem 34 and cable 15. The telemetry modem 32, in the downhole tool 10, applies the control data or command to a timing and control 35 which establishes conditions for the specific task to be performed in the sequence of operations. For example, the timing and control 35 under the computer instructions will establish whether transmitter T1 will be fired by way of transmitter energizer 36 and conductor 37 or whether transmitter T2 is to be fired via the transmitter energizer 36 and conductor 38. The timing and control 35 also establish which of the receiver outputs will be selected and amplified by way of receiver select and amplification means 40. Having now established the downhole tasks to be performed a handshake or sync signal is transmitted from the computer by way of telemetry modem 23 and conductor 41 to the timing control 35 to begin a cycle of the sequence of operations which includes measuring the peak or amplitude of the first halfcycle of the casing signal appearing at the receivers.

While the information concerning the amplitude of the received signals travelling by way of casing can be utilized in the generation of conventional cement bond logs, the amplitude information is processed by the computer in accordance with the present invention to generate an attenuation rate log which more accurately represents the condition or degree of bonding of cement to the casing. In a conventional cement bond log where the amplitude of the received signal is plotted as a function of depth there are a number of conditions or factors that affect the signal and tend to introduce errors in the resultant log. These conditions include receiver sensitivity, transmitter output, borehole temperature variations, drilling fluid condition, formation hardness or velocity and eccentricity or the logging tool.

The effects of these various parameters or conditions can be largely reduced or eliminated by the transmitter and receiver arrangement and physical relationship shown in Figures 1 and 2 operating in conjunction with the method and apparatus of the present invention. For convenience the attenuation due to the drilling fluid may be lumped into a single attenuation factor M which may be assumed to be effective over a lateral portion of the acoustic energy wave path between the casing and the respective transmitters and receivers. In Figure 2 the lump attenuation factor between the transmitters T1 and T2 and the casing have been designated as M1 and M4 whereas the attenuation factor between the receivers R1 and R2 and the casing have been designated as M2 and M3. The factors M1, M2, M3 and M4 can be eliminated by taking a ratio of the acoustic signal amplitudes received at each receiver from one of the transmitters and multiplying this ratio by a similar ratio obtained from a comparison of acoustic signal amplitudes at these receivers from the other transmitter. The various sonic signal amplitudes corresponding to each transmitter-receiver pair are designated T1 R1, T1 R2, T2 R1, T2 R2. The attenuation through the longitudinal zone between the transmitter T1 and the receiver R1 is designated C1 and the transmission over the longitudinal zone between the transmitter T2 and the receiver R2 is designated C2. C3 is the desired attenuation function between the longitudinal zone defined between the receivers R1 and R2. It can be shown by relative simple mathematical manipulation that the undesired transfer or attenuation functions M1, M2, M3 and M4 can be eliminated together with the attenuation functions C1 C2 leaving only the desired attenuation function C3 by taking the product ratio of the amplitudes of signals from the various receivers.

When investigating the media forming a cased well bore, it is important that the logging tool be substantially centered on the borehole. The reason for this concerns the length of the path which acoustic energy must travel between the acoustic transmitter and receiver and the maximum amplitude of the first arrival of the casing signal. The time for acoustic energy to travel through casing to the receiver is known thus enabling a gate to be opened at the appropriate time to measure the peak amplitude of the first energy (the casing signal) arrival at the receiver. The time and amplitude is determined for the case of a centered logging tool. If the logging tool is eccentric in the borehole, the energy emitted from one side of the tool will have a shorter path to and from the casing thus causing the casing arrival at the receiver to be sooner than expected. Thus the above-mentioned gate will not be time centered and the measured casing arrival amplitude will be lower, causing errors in the cement bond log.

However, with the configuration of and operation of transducers shown in Figure 2 the problem introduced by eccentricity is minimized in as much as the same portion of the casing signal from all receivers will be measured.

The determination of attenuation rate in accordance with the present invention, is explained by reference to Figure 2 where the two transmitters T1 and T2 are located symmetrically with respect to the two receivers R1 and R2. At a distance d1 from the upper transmitter T1 the amplitude of the casing-borne sonic wave initiated by transmitter T1 will be attenuated and can be expressed as:

$$A_{11} = P_1 S_1 \quad 10^{-\frac{a}{20} d_1} \quad (1)$$

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where A_{11} is the output of the receiver R_1 in millivolts, P_1 is the pressure amplitude for $d_1 = 0$, S_1 is the receiver sensitivity in millivolts per bar and a is the attenuation rate of the sonic signal in decibels per 0,3048 m (foot). This relationship was established by Pardue, et. al., in an article entitled "Cement Bond Log — A Study of Cement and Casing Variables," appearing in the *Journal of Petroleum Technology*, May, 1963, at page 545. The output of receiver R_2 can be written as:

$$A_{12} = P_1 S_2 10^{-\frac{a}{20} d_2} \quad (2)$$

Similarly, when firing the lower transmitter T_2 , the output of the receivers R_1 and R_2 can be written as:

$$A_{21} = P_2 S_1 10^{-\frac{a}{20} d_2} \quad (3)$$

$$A_{22} = P_2 S_2 10^{-\frac{a}{20} d_1} \quad (4)$$

Utilizing equations (1) to (4) the following ratio is formed:

$$\left[\frac{A_{12} A_{21}}{A_{11} A_{22}} \right] = 10^{\frac{-2a}{20} (d_2 - d_1)} \quad (5)$$

The foregoing relationship shown in equation (5) is called the BHC ratio. From the BHC-ratio (5) the attenuation rate a can be obtained by performing:

$$\frac{-10}{d_2 - d_1} \log_{10} \left[\frac{A_{12} A_{21}}{A_{11} A_{22}} \right] = a \quad (6)$$

where a is expressed in decibels per 0,3048 m (foot). It is to be observed that the measured attenuation is independent of receiver sensitivity, transmitter output power and fluid attenuation for any given sequence of operation.

The BHC attenuation measurement as established by the present invention has a number of advantages over the standard cement bond log measurement and can be summarized as follows. As seen from Figure 2 the sonic signals reaching R_1 or R_2 have travelled the same path through the casing fluid and its effect is thus eliminated while performing the ratio of amplitudes. The fluid attenuation effect can be important in heavy or gas cut muds. The transducer output will ordinarily decrease with increase in temperature and the receiver sensitivity may also decrease with age. This represents a major advance over the prior art systems since it eliminates the need for constant correction or calibration of the receiver outputs for changes in receiver sensitivity which changes are due mostly to temperature effects. These effects are effectively cancelled by utilizing the ratio technique. As mentioned earlier the BHC attenuation or ratio technique is independent of the absolute value of signal level. The measuring range of up to twenty db per foot is only limited by the value of the signal-to-noise ratio. In addition eccentricity of up to 76 mm can be tolerated without having a significant effect upon the accuracy of the measurement.

We have found that the spacing, the physical distance between the transmitters and the receivers is critical in order to obtain an accurate and reliable cement bond log. If the spacing is too long the signal noise ratio suffers to the point where the casing signal is buried in noise and cannot be detected. Even if the spacing is adjusted to enable the detection of the casing signal there are situations where the detected signal does not represent the casing signal. This occurs in situations where the velocity of the surrounding formations is higher than the velocity of sound through casing and where the transmitter to receiver spacing is large the formation signal will appear at the receiver prior to the arrival of the casing signal giving rise to an erroneous measurement.

On the other hand if the receiver to transmitter spacings are too close the errors introduced by eccentricity introduce errors. Accordingly the spacing between the transmitters and the receivers should be such as to provide for a measurable signal-noise-ratio, the arrival of the cement bond signal prior to the arrival of a formation signal and to tolerate eccentricity of as much as 76 mm. The foregoing is accomplished by establishing a distance of approximately 73 cm from the transmitter T_1 to the receiver R_1 and similarly a distance of 73 cm from the transmitter T_2 to the receiver R_2 . The receiver R_2 should be approximately 104 cm from the transmitter T_1 and the receiver R_1 should be approximately 104 cm from

the transmitter T2. The receiver R3 utilized principally in production to a variable density log, is in one embodiment, spaced 152 cm from the transmitter T2.

While the prior art does not include example of sonic logging systems comprising a sonde having a pair of spaced apart receivers included between an upper and a lower receiver, it will be appreciated that these systems were configured for operation in open (i.e., uncased) well bores for detecting formation parameters. These tools have little relevance to the field of cement bond logging due to the very nature of the signal being there measured, i.e., acoustic travel time. The distance between the receivers and transmitters on a sonde are selected to maximize the travel time of acoustic waves through the formation media under investigation relative to the travel time of the acoustic waves between the sonde and the formations. This leads to the selection of relatively large spacings between the receivers and the transmitters. In contrast, for cement bond logging purposes, in accordance with principles of the present invention, the spacings between the transmitters and receivers are selected to enhance not the travel time through the formations but the correlation between the combined output of the receivers and the quality of the cement bond. It will be appreciated that to provide receiver transmitter spacings of the order of those provided in tools configured for open hole logging purposes while appearing to be quite acceptable is actually detrimental to the operation of the system in cased holes since by the very nature of the measurement, the noise content of the signal in cased holes will increase proportionately with the distance between the receiver and the transmitter. Therefore, the choice of transmitter to receiver spacings is crucial to the realization of the advantages of the present invention.

Referring to Figure 1 there will now be described the system for acquiring the casing signal data for use in the relationship defined by expression (8). Upon instructions from computer 30 to timing and control 35 a handshake or sync signals follows. The timing and control 35 now sends a firing command to the transmitter energizer 36 by way of conductor 42 for the generation by transmitter T1 of acoustic energy which travels outwardly through the drilling fluid and is refracted along the casing and back through the drilling fluid to receiver R1. The output of receiver R1 is applied by way of conductor 43 to the receiver select and amplification means 40 whose output, an analog signal, is transmitted uphole by way of conductor 44 telemetry modem 23 cable 15 telemetry modem 34 to the monitor oscilloscope 50. The analog output from the receiver select and amplification means 40 is also applied to the amplitude and transit time detection means 51 where the peak amplitude of the casing signal is detected and the transit time of the signal determined.

A typical waveform for casing signals arriving at receivers under different cement bond conditions is illustrated in Figure 3. It will be observed that where the casing is unbonded the halfcycles of the waveform comprising peaks E1, E2 and E3 are significantly greater than the amplitude of the corresponding peaks under conditions where the casing is well bonded to the cement. The halfcycle whose peak is to be detected is optional with the operator who, having knowledge of the transit time of acoustic energy through casing as well as the distance between the transmitter and the selected receiver, can establish by way of the computer an effective gate onset which is implemented by way of the timing and control 35 which conditions the amplitude and transit time detection means 51 to measure the peak amplitude of a selected halfcycle of the casing signal. Typically, the amplitude of peak E1 is detected.

Transit times detection or measurement is effected also by way of a control pulse from the timing and control means 35 applied by way of conductor 54 to the amplitude and transit time detection means 51 which control pulse signifies the time at which the transmitter T1 has been fired. Utilizing conventional timing circuits in the means 51 a digital signal is produced representative of the value of the transit time for acoustic energy to travel from the transmitter T1 to the receiver R1. This digital signal is applied directly by way of conductor 55 to the telemetry modem 23 for transmission to the surface.

The analog signal representative of the peak amplitude of the detected casing signal is applied by way of conductor 56 to the multiplex and A/D converter 60 whose digital output is also applied to telemetry modem 23 for transmission to the surface.

The transit time signal is processed by the computer 30 converted to an analog signal and is available, at the option of the operator, to be recorded by the analog recorder 61 as a function of depth; the depth function as previously described being generated by conventional means also being processed by the computer and utilized to displace the data with respect to the recording medium. The digital representation of the detected amplitude of the casing signal is momentarily stored by the computer 30 to be utilized in conjunction with other data to generate a signal representative of attenuation rate in accordance with the present invention.

The system having performed the first cycle in the sequence the computer 30 now sends additional instructions to the timing and control means in the manner above described once again to fire transmitter T1 and effectively now to connect the output of receiver R2 to the receiver select and amplification means 30. Again there is detected the amplitude of a casing signal arriving at receiver R2 and the transit time of that signal between the transmitter T1 and the receiver R2. The transit time may be recorded at the analog recorder 62 as a function of depth and again the digital value of the amplitude of the received casing signal is stored in the computer 30.

In the next cycle of the sequence, instructions are transmitted from the computer 30 to the timing and control means 35 to establish conditions for the firing of the transmitter T2 and for the connection of the receiver R2. Upon the handshake by way of conductor 41, the transmitter T2 fired and acoustic energy

travelling by way of the casing is detected at the receiver R2 where the peak amplitude E1 of the first halfcycle is detected by the amplitude detector 51 and applied by way of conductor 56 where it is converted to a digital signal in the multiplex and A/D converter 60 and transmitted uphole for storage in the computer 30. The transit time of the energy between the transmitter T2 and the receiver R2 is also measured or detected in the manner aforesaid and transmitted uphole.

Upon further instructions from the computer 30 and following the handshake signal the transmitter T2 again fires and the energy received at the receiver R2 by way of the casing is applied by way of conductor 43 to the receiver select and amplification 40 where again the analog representation of the signal is transmitted over conductor 44 by way of telemetry modem 32 to the uphole monitor oscilloscope 50. In the manner above described the amplitude of the first halfcycle of the energy arriving by way of the casing is detected and applied to the multiplex and A/D converter for transmission to the computer 30 and the transit time is detected and the digital representation from the amplitude and transit time detection means 51 is applied to the telemetry modem 23 by way of conductor 55 for transmission uphole to the computer 30 for recording, if desired, on the analog recorder 62.

Now in the final stage of the sequence as it relates to the generation of acoustic energy and detection after travel by way of the casing the transmitter T2 is again fired and the output of receiver R3 is applied by way of conductor 65 and the receiver select and amplification means 40 to the telemetry modem 23 by way of conductor 44. The signal or wave train from the receiver R3 is utilized for the production of a variable density log in a manner well known in the art.

Thus where the recorder 62 is comprised of an oscilloscope and photographic film, such a log is produced by sweeping an electron beam across the face of the oscilloscope and modulating the beam intensity with the received acoustic energy waveform while moving the film, as a function of depth of the logging tool, past the face of the oscilloscope. A typical variable density log is illustrated in Figure 4 of U.S. Patent No. 3,696,884.

This now completes the sequence of operations which are comprised in the acoustical detection of five cycles namely T1 to R1, T1 to R2, T2 to R2, T2 to R1, and T2 to R3. Each cycle requires control information to be transmitted from the computer 30 to the downhole equipment followed by a handshake. The handshake is the sync signal that informs the downhole equipment to execute the instructions. Following the acquisition of casing signal amplitude for each sequence, computer 30 produces an attenuation rate signal in accordance with the relationship defined by expression (6) and this signal is recorded as a function of depth of the logging tool by recorder 62.

The downhole tool also includes the collar detector 21 and the natural gamma ray detector 22. The outputs of these detectors are shown being applied by way of conductor 70 to the multiplex and A/D converter 60 which is under control of the timing and control means 35. The digital representations of these signals which fire the five cycles of the acoustic mode of operation are applied uphole by way of the telemetry modem 23 cable 15 to the computer where they are processed and recorded as a function of depth by the analog recorder 62. The parameters of natural gamma ray and collar detector are useful in correlating the resulting cement bond log with other logs previously taken in open hole.

In the system of Figure 1, the transmitters T1 and T2 are fired four times in each sequence of casing signal amplitude measurement. It is possible that between successive firing of the transmitter T1 or successive firing of the transmitter T2 the output of either transmitter may change. In that event an error would be introduced to the ratio determination. Such error, due to sudden variation in transmitter output can be avoided by way of a method in which signals from receivers R1 and R2 are produced for each firing of transmitter T1. Likewise signals from receivers R2 and R1 would be produced for each firing of the transmitter T2. The system of Figure 1 would be modified to include a second amplitude and transit time detection means like that means 51. In such event the receiver select 40 would connect receiver R1 to one of the detection means and connect receiver R2 to the other of the detection means. Therefore, each transmitter firing results in the production of two receiver signals utilized in a ratio relationship and accordingly the operation avoids the introduction of error due to any types of changes in transmitter output.

It will be recalled that the system of Figure 1 provides for the determination of acoustic transit time between transmitters and receivers and the recording of same. This information is useful where hard formations may be encountered. In formations where the travel time is less than 187 microseconds per meter the 104 cm amplitude measurement is no longer valid. Indeed neither is a measurement taken with a transmitter to receiver spacing of 91 cm. Under such conditions the formation signal travelling behind the cement sheath precedes and superimposes itself on the casing-borne signal. It is now impossible to measure the attenuation rate due to the casing-cement bond with the transducer spacings described.

Shorter transducer spacing would seem dictated when measuring attenuation rate in the environment of a hard or fast formation. However, shorter spacing introduces error due to eccentricity. The shorter the T to R spacing the more pronounced is the eccentricity effect.

Since under such fast formation conditions, attenuation rate measurement is impractical, rather than stop the gathering of data, advantage is taken of the physical position of the receiver R3 to continue to obtain some measure of cement bond conditions. The receiver R3 has been placed 5 feet from transmitter T2 for the purpose of obtaining a standard variable density log. This places receiver R3 approximately 24 cm from transmitter T1. We have determined that at this spacing, the first arriving signal will be the casing

signal even where the the formation traveltime is as low as 47 microseconds per 0,3048 m (foot).

The operator, in the course of the logging operation, will observe the value of transit time between a selected pair of transmitter and receiver. When the observed transit time falls below the transit time of acoustic energy in casing the computer 30 will be instructed via terminal 32 to change the sequence of downhole operations. The sytem operation will be modified to produce a conventional cement bond log where the peak of the first halfcycle of signal from receiver R3 in response to acoustic energy from transmitter T1 will be detected by the amplitude detection means 51 and recorded by recorder 62.

When the foregoing operations are being conducted to produce the conventional cement bond log transmitter output variation poses a problem. In accordance with another aspect of the present invention errors introduced by variations in transmitter output are circumvented. More particularly the output of the receivers is modified as a function of transmitter output.

The downhole system includes a transmitter energy detector which provides a measure of the energy being generated by the transmitters T1 and T2 each time they are fired. The measurement is of the voltage being applied to the transmitters by the transmitter energizer 36. For example, a typical voltage applied to each transmitter is approximately 1500 volts. Should the voltage output of the energizer vary and drop to as low as 750 volts between successive firings of the transmitter T1 the detected peak amplitude of the received signal will also drop resulting in an error.

A measure of transmitter voltage (TV) is produced in the transmitter energizer 36 and applied by way of conductor 75 to the multiplex and A/D converter 60. The digital value of the measured transmitter voltage is utilized by computer 30 in accordance with the following expression:

$$A'13 \frac{A13}{G} \times \frac{1500}{TV} \quad (7)$$

where:

A'13 is the amplitude of the signal to be recorded or otherwise used,
A13 is the measured signal amplitude, and
G is the gain of the amplification means 40.

The above described modification of the receiver signal as a function of transmitter voltage gives rise to more accurate conventional type cement bond logs and may be utilized in systems other than illustrated in Figure 1. It is also valuable in the ratio method where the possibility exists of fluctuations in transmitter voltage between successive firing of a given transmitter. Accordingly the system of Figure 1 is arranged to be operated in such manner as to sense the value of the transmitter voltage for each firing of the transmitters T1 and T2 and each received signal is modified by a factor comprised of the ratio of the predetermined transmitter voltage to the measured transmitter voltage.

In the discussion above reference was made to eccentricing and problems introduced when eccentricing became significantly high. The present system can produce an accurate attenuation rate log where the eccentricing is as great as 76 mm. Maintaining this limit becomes a problem in deviated wells where the deviation is in excess of 20 degrees. In those instances the weight of the logging tool is increasingly applied against the centralizers causing the tool to move away from a centered position to a position close to the casing. The eccentricing problem is materially reduced by utilizing the logging tool of Figure 4. This arrangement makes it possible to maintain the tool to within 76 mm of the casing axis where the well deviation is as great as 90 degrees. The lower portion 80 of the tool houses the transmitters T1 and T2 and the receivers R1, R2 and R3. The lower portion 80 is maintained centrally of the casing by means of in-line centralizers 81 and 82 each respectively having wheels 84 and 83 to ease the passage of the tool along the casing.

The lower portion 80 is, in and of itself, light enough to avoid significantly compressing the centralizers 81 and 82 even when the portion is in a horizontal position, i.e., a well deviation of 90 degrees. The light weight is maintained by effectively mechanically decoupling the lower portion 80 from the remainder of the logging tool. The decoupling is provided by two flex joints 91 and 92 located between cartridge 90 and the lower portion 80. The articulation provided by the flex joints renders the lower portion free from lateral excursions of the cartridge 90 and other upper portions of the logging tool due to forces including gravity.

The cement bond tool is a 70 mm size logging tool rated at 173°C and 1450 bar. That portion of the tool housing the transducers is light, about 45 kg, and made rigid. The optimum transmitter to receiver separation was set at 73 cm and 104 cm for the near and for the receivers, respectively. A separate receiver was set at 5 feet from the lower transmitter to provide data for a variable density log. This same receiver spaced 76 mm from the upper transmitter provides data for a conventional cement bond log when logging through fast formations. The computer 30 used in one embodiment is a PDP 1134.

Referring now to Figure 5 there are shown examples of the BHC attenuation log, produced in accordance with the present invention, as well as natural gamma log, a collar locator log and a transit time log. The transit time log is fairly constant in value indicating that the detecting signals are casing-borne. Not unexpeced in the transit time log are abrupt changes which are due to malfunction and known in the art of cycle skipping. The attenuation rate log shows at a depth of 395 m a very low attenuation rate indicative of a poor cement bond. Any measure above 33 db/m would indicate a good cement bond. Values less than 33 db/m may be acceptable, and certainly low values of attenuation rate should raise a question concerning the competency of the cement bond.

Claims

1. A method for obtaining a measure of quality of a cement bond relative to a casing in a borehole comprising the steps of:
- 5 establishing in a well tool having two longitudinally spaced acoustic transmitters and at least two longitudinally spaced acoustic receivers disposed between said acoustic transmitters with a transmitter receiver spacing to provide for a measurable signal-noise-ratio, the arrival of a casing signal prior to the arrival of a formation signal and to tolerate eccentricity of as much as 76 mm;
- repetitively energizing said acoustic transmitters to apply acoustic energy into the casing surrounding
- 10 said well tool;
- detecting at said receivers energy from a first of said transmitters arriving at said receivers by way of said casing;
- detecting at said receivers acoustic energy arriving by way of said casing from a second of said transmitters following the firing of said first transmitter;
- 15 for each of the foregoing generations and detections measuring the peak amplitude of a selected portion of the acoustic casing signals detected at each of said receivers;
- obtaining a ratio of the peak amplitudes associated with the firing of said first transmitter;
- obtaining a ratio of the peak amplitude associated with the firing of said second transmitter;
- combining said ratios to produce a function representative of the attenuation of acoustic energy
- 20 travelling through the casing;
- and recording said attenuation as a function of tool position in the borehole.
2. The method of claim 1 characterized in that said transmitters are each fired twice to generate four acoustic pulses and peak amplitudes of the resulting four casing signals are detected.
3. The method of claim 1 characterized in that said transmitters are each fired once to generate two
- 25 acoustic pulses and each resulting casing signal is detected by both receivers.
4. The method of claim 2 characterized in that a firing voltage is applied to excite a transmitter, measuring the value of said voltage,
- comparing said measured value with a predetermined value of voltage to produce a modifying function, and
- 30 applying said modifying function to the peak amplitude of the casing signal resulting from the firing of said transmitter to correct for variations in the value of said firing voltage.
5. The method of claim 4 characterized in that the modifying function is the ratio of the predetermined value of the voltage to the measured value of the voltage.
6. The method of any one of claims 1-5 characterized in that said attenuation a is determined by
- 35 combining said ratios of peak amplitude in accordance with the following expression:

$$40 \quad \frac{-10}{d2-d1} \log_{10} \left[\frac{A_{12} A_{21}}{A_{11} A_{22}} \right] = a$$

where:

- d1 is the distance between a transmitter and a near receiver,
- 45 d2 is the distance between a transmitter and a far receiver,
- A_{11} is the peak amplitude of the casing signal from the first transmitter to the first receiver,
- A_{12} is the peak amplitude of the casing signal from the first transmitter to the second receiver,
- A_{21} is the peak amplitude of the casing signal from the second transmitter to the first receiver, and
- 50 A_{22} is the peak amplitude of the casing signal from the second transmitter to the second receiver.
7. The method of claim 1 characterized in that said well tool includes a third acoustic receiver located between said first of said transmitters and an adjacent receiver comprising the steps of
- measuring the transit time of acoustic energy between said transmitters and at least one of said two receivers,
- comparing the measured transit time with a known value of transit time of acoustic energy through
- 55 said casing,
- upon said measured transit time falling to a predetermined value less than the transit time through casing detecting the peak amplitude of the first halfcycle of acoustic energy appearing at said third receiver following excitation of said first transmitter, and
- recording said peak amplitude as a function of tool position in the borehole.
- 60 8. The method of claim 7 characterized in that a firing voltage is applied to excite said first transmitter, measuring the value of said firing voltage,
- comparing said measured value with a predetermined value of voltage to produce a modifying function, and
- applying said modifying function to the peak amplitude to correct for variation in the value of said
- 65 firing voltage.

9. Apparatus for obtaining a measure of quality of a cement bond relative to a casing in a borehole characterized by:
- a well tool having two longitudinally spaced acoustic transmitters (T1, T2) and at least two longitudinally spaced acoustic receivers (R1, R2) disposed between said acoustic transmitters;
 - 5 said receivers being respectively spaced approximately 73 cm and 104 cm from each transmitter;
 - means (36) for repetitively energizing said acoustic transmitters to apply acoustic energy into the casing surrounding said well tool;
 - said receivers detecting energy from a first of said transmitters arriving at said receivers by way of said casing;
 - 10 said receivers detecting energy arriving by way of said casing from a second of said transmitters following the firing of said first transmitter;
 - means (50) for measuring the peak amplitude of a selected portion of the acoustic casing signal detected at each of said receivers;
 - means (30) for obtaining a ratio of the peak amplitudes associated with the firing of said first transmitter;
 - 15 means (30) for obtaining a ratio of the peak amplitude associated with the firing of said second transmitter;
 - means (30) for combining said ratios to produce a function representative of the attenuation of acoustic energy travelling through the casing; and
 - 20 means (62, 63) for recording said attenuation rate as a function of tool position in the borehole.
10. Apparatus of claim 9 characterized by:
- a third receiver (R3) located between one of said transmitters and said two spaced receivers;
 - means (51) for measuring the transit time of acoustic energy arriving at at least one of said receivers;
 - means (30) for comparing said measure transit time with a known transit time of acoustic energy
 - 25 through the casing under investigation;
 - means (30) for obtaining the peak amplitude of the first halfcycle of acoustic energy appearing at the third receiver following excitation of said one transmitter upon the measured transit time falling below the value of said known transit time, and
 - means (62, 63) for recording said peak amplitude as a function of tool position in the borehole.
- 30 11. Apparatus of claim 10 characterized in that said third receiver (R3) located about 24 cm from one said transmitter (T1) and about 152 cm from said other transmitter (T2).

Patentansprüche

- 35 1. Ein Verfahren für das Gewinnen einer Messung der Qualität einer Zementierung relativ zu einer Auskleidung in einem Bohrloch, umfassend die Schritte:
- Bewirken, in einer Bohrlochsonde mit zwei in Längsrichtung beabstandeten akustischen Sendern und mindestens zwei in Längsrichtung beabstandeten akustischen Empfängern, die zwischen den genannten akustischen Sendern angeordnet sind, mit einem Sender-Empfänger-Abstand zum Vorsehen eines
- 40 meßbaren Signal-Rausch-Verhältnisses, des Eintreffens eines Auskleidungssignals von dem Eintreffen eines Formationssignals und zum Tolerieren des Exzentrierens von bis zu 76 mm,
- wiederholtes Erregen der akustischen Sender zum Einspeisen akustischer Energie in die das Bohrloch umgebende Auskleidung,
- Erfassen an den Empfängern von Energie von einem ersten der genannten Sender, welche Energie an
- 45 den genannten Empfängern aus dem Weg über die genannte Auskleidung eintrifft,
- Erfassen an den Empfängern von akustischer Energie, die eintrifft auf dem Weg über die Auskleidung von einem zweiten der Sender nach dem Erregen des ersten Senders,
- für jede der vorgenannten Erzeugungen und Erfassungen: Messen der Spitzenamplitude eines ausgewählten Abschnitts der akustischen Auskleidungssignale, erfaßt an jedem der genannten
- 50 Empfänger,
- Gewinnen eines Verhältnisses der Spitzenamplituden, assoziiert mit dem Erregen des genannten ersten Senders,
- Gewinnen eines Verhältnisses der Spitzenamplitude, assoziiert mit der Erregung des genannten zweiten Senders,
- 55 Kombinieren der genannten Verhältnisse zum Erzeugen einer Funktion, die repräsentativ ist für die Dämpfung der durch die Auskleidung laufenden akustischen Energie und
- Aufzeichnen der genannten Dämpfung als eine Funktion der Sondenposition im Bohrloch.
2. Das Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß jeder der genannten Sender zweimal erregt wird zum Erzeugen von vier akustischen Impulsen und die Spitzenamplituden der resultierenden
- 60 vier Auskleidungssignale erfaßt werden.
3. Das Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß die genannten Sender jeweils einmal erregt werden zum Erzeugen von zwei akustischen Impulsen und wobei jedes resultierende Auskleidungssignal durch beide Empfänger erfaßt wird.
4. Das Verfahren nach Anspruch 2, dadurch gekennzeichnet; daß eine Erregungsspannung angelegt
- 65 wird zum Erregen eines Senders, daß der Wert der genannten Spannung gemessen wird, daß der

gemessene Wert verglichen wird mit einem vorgegebenen Wert der der Spannung zum Erzeugen einer Modifikationsfunktion und daß die genannte Modifikationsfunktion auf die Spitzenamplitude des Auskleidungssignal angewandt wird, resultierend von der Erregung des genannten Senders zwecks Korrektur bezüglich Variationen im Wert der genannten Erregungsspannung.

5 5. Das Verfahren nach Anspruch 4, dadurch gekennzeichnet, daß die Modifikationsfunktion das Verhältnis des vorgegebenen Wertes der Spannung zu dem gemessenen Wert der Spannung ist.

6. Das Verfahren nach einem der Ansprüche 1 bis 5, dadurch gekennzeichnet, daß die genannte Dämpfung a bestimmt wird durch Kombination der Verhältnisse der Spitzenamplitude gemäß folgendem Ausdruck:

$$10 \quad \frac{-10}{d_2 - d_1} \log_{10} \left[\frac{A_{12} A_{21}}{A_{11} A_{22}} \right] = a$$

15 worin

d_1 der Abstand zwischen einem Sender und einem nahem Empfänger ist,

d_2 der Abstand zwischen einem Sender und einem fernen Empfänger ist,

A_{11} die Spitzenamplitude des Auskleidungssignals von dem ersten Sender zum ersten Empfänger ist,

A_{12} die Spitzenamplitude des Auskleidungssignals von ersten Sender zum ersten Empfänger ist,

20 A_{21} die Spitzenamplitude des Auskleidungssignals von zweiten Sender zum ersten Empfänger ist, und

A_{22} die Spitzenamplitude des Auskleidungssignals von zweiten Sender zum ersten Empfänger ist.

7. Das Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß die genannte Bohrlochsonde einen dritten akustischen Empfänger aufweist, positioniert zwischen einem ersten der genannten Sender und einem nahen Empfänger, umfassend die Schritte:

25 Messen der Laufzeit der akustischen Energie zwischen den genannten Sendern und mindestens einem der genannten beiden Empfänger; Vergleichen der gemessenen Laufzeit mit einem bekannten Laufzeitwert akustischer Energie durch die genannte Auskleidung, wenn die genannte gemessene Laufzeit auf einen vorgegebenen Wert fällt, der kleiner ist als die Laufzeit durch die Auskleidung; Erfassen der Spitzenamplitude des ersten Halbzyklus akustischer Energie, erscheinend an dem genannten dritten Empfänger nach Erregung des genannten ersten Senders und

Aufzeichnen der genannten Spitzenamplitude als eine Funktion der Sondenposition im Bohrloch.

8. Das Verfahren nach Anspruch 7, dadurch gekennzeichnet, daß eine Erregungsspannung zum Erregen des genannten ersten Senders angelegt wird,

Messen des Wertes der genannten Erregungsspannung,

35 Vergleichen des genannten gemessenen Werts mit einem vorgegebenen Wert der Spannung zum Erzeugen einer Modifikationsfunktion und

Anwenden der genannten Modifikationsfunktion auf die Spitzenamplitude zum Korrigieren bezüglich Veränderungen im Wert der genannten Erregungsspannung.

9. Vorrichtung für das Gewinnen einer Messung der Qualität einer Zementierung bezüglich einer

40 Auskleidung in einem Bohrloch, gekennzeichnet durch:

eine Bohrlochsonde mit zwei in Längsrichtung beabstandeten akustischen Sendern (T1, T2) und mindestens zwei in Längsrichtung beabstandeten akustischen Empfängern (R1, R2), die zwischen den genannten akustischen Sendern angeordnet sind,

welche Empfänger jeweils etwa 73 cm bzw. 104 cm von jedem Sender beabstandet sind,

45 Mittel (36) für wiederholtes Erregen der akustischen Sender zum Einspeisen akustischer Energie in die die genannte Bohrlochsonde umgebende Auskleidung,

welche Empfänger Energie erfassen von einem ersten der genannten Sender, die an den genannten Empfängern auf dem Weg über die Auskleidung eintreffen,

wobei die genannten Empfänger Energie erfassen, die eintrifft auf dem Weg über die Auskleidung von

50 einem zweiten der genannten Sender nach dem Erregen des ersten Senders,

Mittel (50) für das Messen der Spitzenamplitude eines ausgewählten Abschnitts des akustischen Auskleidungssignals, erfaßt an jedem der genannten Empfänger,

Mittel (30) für das Gewinnen eines Verhältnisses der Spitzenamplituden, assoziiert mit der Erregung des genannten ersten Senders,

55 Mittel (30) für das Gewinnen eines Verhältnisses der Spitzenamplitude, assoziiert mit der Erregung des genannten ersten Senders,

Mittel (30) für das Kombinieren der Verhältnisse zum Erzeugen einer Funktion, die repräsentativ ist für die Dämpfung der akustische Energie, welche durch die Auskleidung läuft, und

Mittel (62, 63) für das Aufzeichnen der genannten Dämpfungsrate als eine Funktion der Sondenposition

60 im Bohrloch.

10. Vorrichtung nach Anspruch 9, gekennzeichnet durch

einem dritten Empfänger (R3), positioniert zwischen einem der genannten Sender und den genannten beiden beabstandeten Empfängern,

65 Mittel (51) für die Messung der Laufzeit akustischer Energie, die eintrifft an mindestens einem der genannten Empfänger,

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Mittel (30) für das Vergleichen der genannten gemessenen Laufzeit mit einer bekannten Laufzeit akustischer Energie durch die Auskleidung, die untersucht wird,

Mittel (30) für das Gewinnen der Spitzenamplitude des ersten Halbzyklus von akustischer Energie, die an dem dritten Empfänger erscheint nach Erregung des genannten eines Senders, wenn die gemessene Laufzeit unter den Wert der genannten bekannten Laufzeit fällt und

Mittel (62, 63) für das Aufzeichnen der genannten Spitzenamplitude als eine Funktion der Sondenposition im Bohrloch.

11. Vorrichtung nach Anspruch 10, dadurch gekennzeichnet, daß der genannte dritte Empfänger (R3) etwa 24 cm von dem genannten einen Sender (T1) entfernt ist und etwa 152 cm von dem genannten anderen Sender (T2).

Revendications

1. Un procédé pour obtenir une mesure de qualité d'un cimentage relatif à un tubage dans un puits de forage comprenant les étapes consistant à:

établir dans un outil de puits possédant deux transmetteurs acoustiques espacés longitudinalement et au moins deux récepteurs acoustiques espacés longitudinalement disposés entre lesdits transmetteurs acoustiques avec un espacement transmetteur récepteur pour produire un rapport signal-bruit mesurable, l'arrivée d'un signal de tubage antérieure à l'arrivée d'un signal de formation et pour tolérer une excentration atteignant 76 mm;

exciter de façon répétitive lesdits transmetteurs acoustiques pour appliquer une énergie acoustique dans le tubage entourant ledit outil de puits;

détecter auxdits récepteurs un énergie provenant d'un premier desdits transmetteurs arrivant auxdits récepteurs par ledit tubage;

détecter auxdits récepteurs une énergie acoustique arrivant par ledit tubage provenant d'un second desdits transmetteurs suivant la mise en action dudit premier transmetteur;

mesurer, pour chacune des productions et détections précédentes, l'amplitude maximum d'une partie sélectionnée des signaux de tubage acoustiques détectés à chacun desdits récepteurs;

obtenir un rapport des amplitudes maximum associées à la mise en action dudit premier transmetteur;

obtenir un rapport de l'amplitude maximum associée à la mise en action dudit second transmetteur;

combiner lesdits rapports pour produire une fonction représentative de l'atténuation de l'énergie acoustique se propageant à travers le tubage; et

enregistrer ladite atténuation en fonction de la position de l'outil dans le puits de forage;

2. Le procédé de la revendication 1 caractérisé en ce que lesdits transmetteurs sont chacun mis en action deux fois pour produire quatre impulsions acoustiques et les amplitudes maximum des quatre signaux de tubage résultants sont détectées.

3. Le procédé de la revendication 1 caractérisé en ce que lesdits transmetteurs sont chacun mis en action une fois pour produire deux impulsions acoustiques et chaque signal de tubage résultant est détecté par les deux récepteurs.

4. Le procédé de la revendication 2 caractérisé en ce qu'une tension de mise en action est appliquée pour exciter un transmetteur,

on mesure la valeur de cette tension,

on compare ladite valeur mesure ze avec une valeur prédéterminée de tension pour produire une fonction de modification, et

on applique ladite fonction de modification à l'amplitude maximum du signal de tubage résultant de la mise en action dudit transmetteur pour corriger les variations dans la valeur de ladite tension de mise en action.

5. Le procédé de la revendication 4 caractérisé en ce que la fonction de modification est le rapport de la valeur prédéterminée de la tension à la valeur mesurée de la tension.

6. Le procédé de l'une quelconque des revendications 1 à 5 caractérisé en ce que ladite atténuation a est déterminée en combinant lesdits rapports d'amplitude maximum selon l'expression suivante:

$$\frac{-10}{d2-d1} \log_{10} \left[\frac{A12}{A11} \frac{A21}{A22} \right] = a$$

où

$d1$ est la distance entre un transmetteur et un récepteur proche,

$d2$ est la distance entre un transmetteur et un récepteur éloigné,

$A11$ est l'amplitude maximum du signal de tubage provenant du premier transmetteur sur le premier récepteur,

$A12$ est l'amplitude maximum du signal de tubage provenant du premier transmetteur sur le second récepteur,

$A21$ est l'amplitude maximum du signal de tubage provenant du second transmetteur sur le premier récepteur,

A22 est l'amplitude maximum du signal de tubage provenant du second transmetteur sur le second récepteur.

7. Le procédé de la revendication 1 caractérise en ce que ledit outil de puits comprend un troisième récepteur acoustique placé entre en premier desdits transmetteurs et un récepteur adjacent comprenant

les étapes consistant à:
mesurer le temps de transit de l'énergie acoustique entre lesdits transmetteurs et au moins un des deux dits récepteurs,

comparer le temps de transit mesuré avec un valeur connue de temps de transit de l'énergie acoustique à travers ledit tubage,

lorsque ledit temps de transit mesuré tombe à une valeur prédéterminée inférieure au temps de transit à travers le tubage, détecter l'amplitude maximum de premier demi-cycle d'énergie acoustique apparaissant audit troisième récepteur suivant l'excitation dudit premier transmetteur, et enregistrer cette amplitude maximum en fonction de la position de l'outil dans le puits de forage.

8. Le procédé de la revendication 7 caractérise en ce qu'une tension de mise en action est appliquée pour exciter ledit premier transmetteur,

on mesure la valeur de ladite tension de mise en action,
on compare ladite valeur mesurée avec un valeur prédéterminée de tension pour produire une fonction de modification, et

on applique ladite fonction de modification à l'amplitude maximum pour corriger les variations dans la valeur de ladite tension de mise en action.

9. Dispositif pour obtenir une mesure de qualité d'un cimentage relatif à un tubage dans une puits de forage caractérisé par:

un outil de puits possédant deux transmetteurs acoustiques espacés longitudinalement (T1, T2) et au moins deux récepteurs acoustiques espacés longitudinalement (R1, R2) disposés entre lesdits transmetteurs acoustiques;

lesdites récepteurs étant respectivement espacés approximativement de 73 cm et 104 cm de chaque transmetteur;

des moyens (36) pour exciter de façon répétitive lesdits transmetteurs acoustiques pour appliquer une énergie acoustique dans le tubage entourant ledit outil de puits;

lesdits récepteurs détectant une énergie provenant d'un premier desdits transmetteurs arrivant auxdits récepteurs par ledit tubage;

lesdits récepteurs détectant une énergie arrivant par ledit tubage provenant d'un second desdits transmetteurs suivant la mise en action dudit premier transmetteur;

des moyens (50) pour mesurer l'amplitude maximum d'une partie sélectionnée des signaux de tubage acoustiques détectés à chacun desdits récepteurs;

des moyens (30) pour obtenir un rapport des amplitudes maximum associées à la mise en action dudit premier transmetteur;

des moyens (30) pour obtenir un rapport de l'amplitude maximum associée à la mise en action dudit second transmetteur;

des moyens (30) pour combiner lesdits rapports pour produire une fonction représentative de l'atténuation de l'énergie acoustique se propageant à travers le tubage; et

des moyens (62, 63) pour enregistrer ledit taux d'atténuation en fonction de la position de l'outil dans le puits de forage.

10. Dispositif selon la revendication 9 caractérisé par:

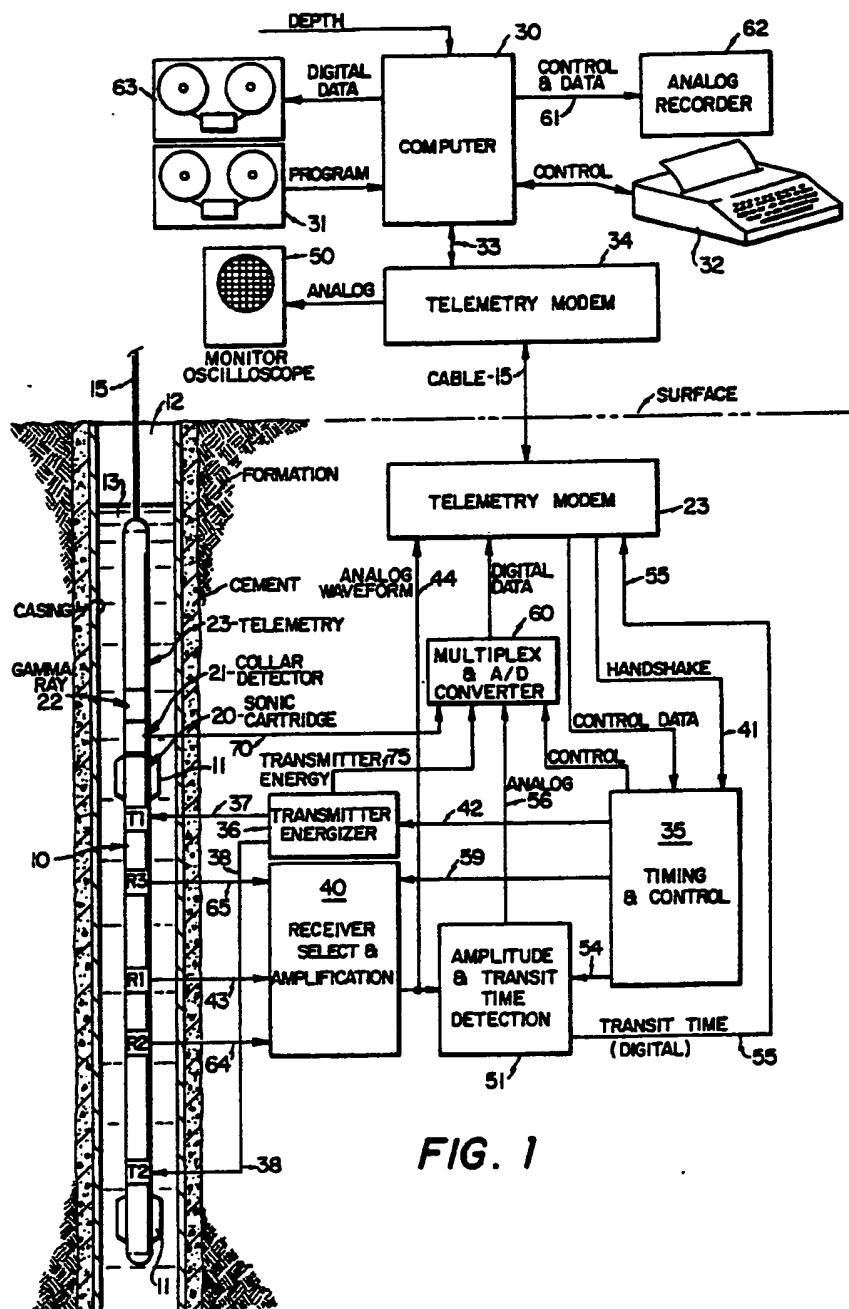
un troisième récepteur (R3) placé entre l'un desdits transmetteurs et lesdits deux récepteurs espacés;
des moyens (51) pour mesurer le temps de transit de l'énergie acoustique arrivant à l'un au moins desdits récepteurs;

des moyens (30) pour comparer ledit temps de transit mesuré avec un temps de transit connu de l'énergie acoustique à travers le tubage en cours d'étude;

des moyens (30) pour obtenir l'amplitude maximum du premier demi-cycle de l'énergie acoustique apparaissant au troisième récepteur suivant l'excitation dudit transmetteur lorsque le temps de transit mesuré tombe au dessous de la valeur dudit temps de transit connu, est

des moyens (62, 63) pour enregistrer l'amplitude maximum en fonction de la position de l'outil dans le puits de forage.

11. Appareil de la revendication 10 caractérisé en ce que ledit troisième récepteur (R3) est placé à environ 24 cm dudit transmetteur (T1) et à environ 152 cm dudit autre transmetteur (T2).



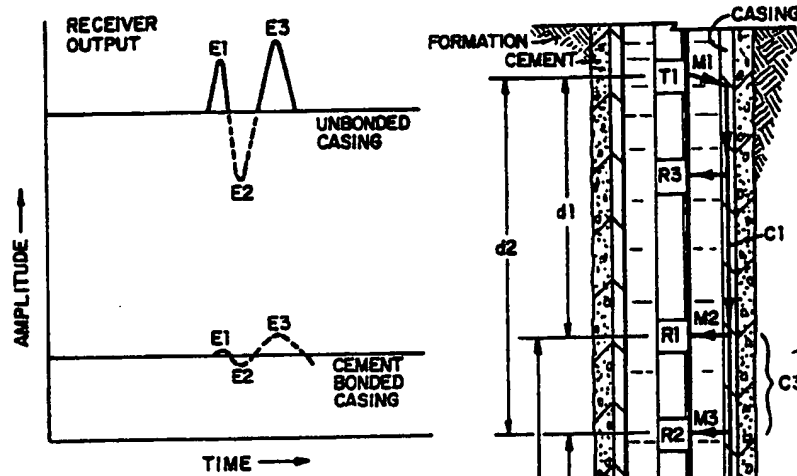


FIG. 3

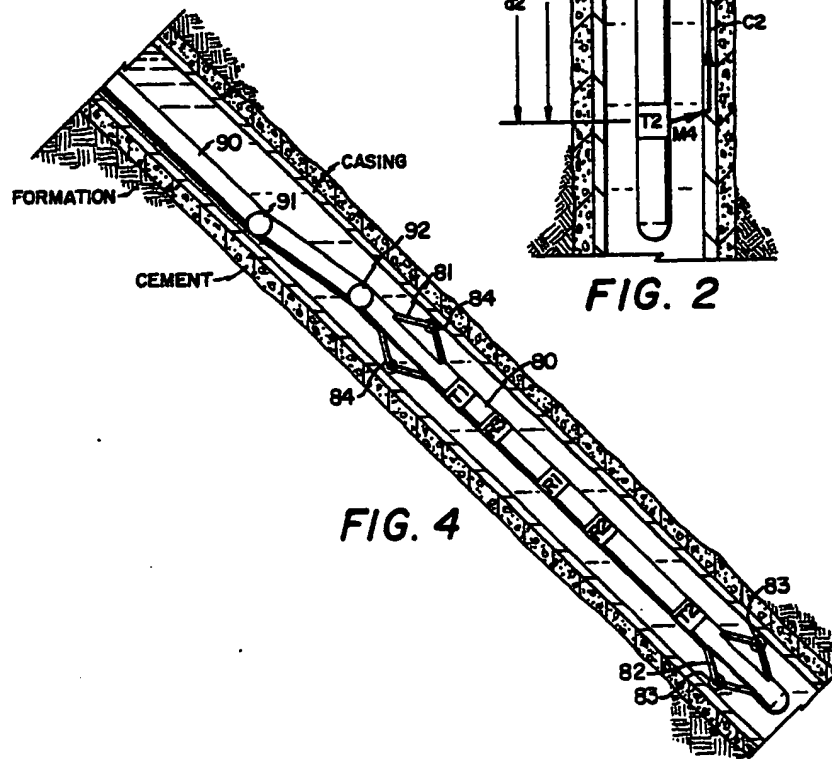


FIG. 4

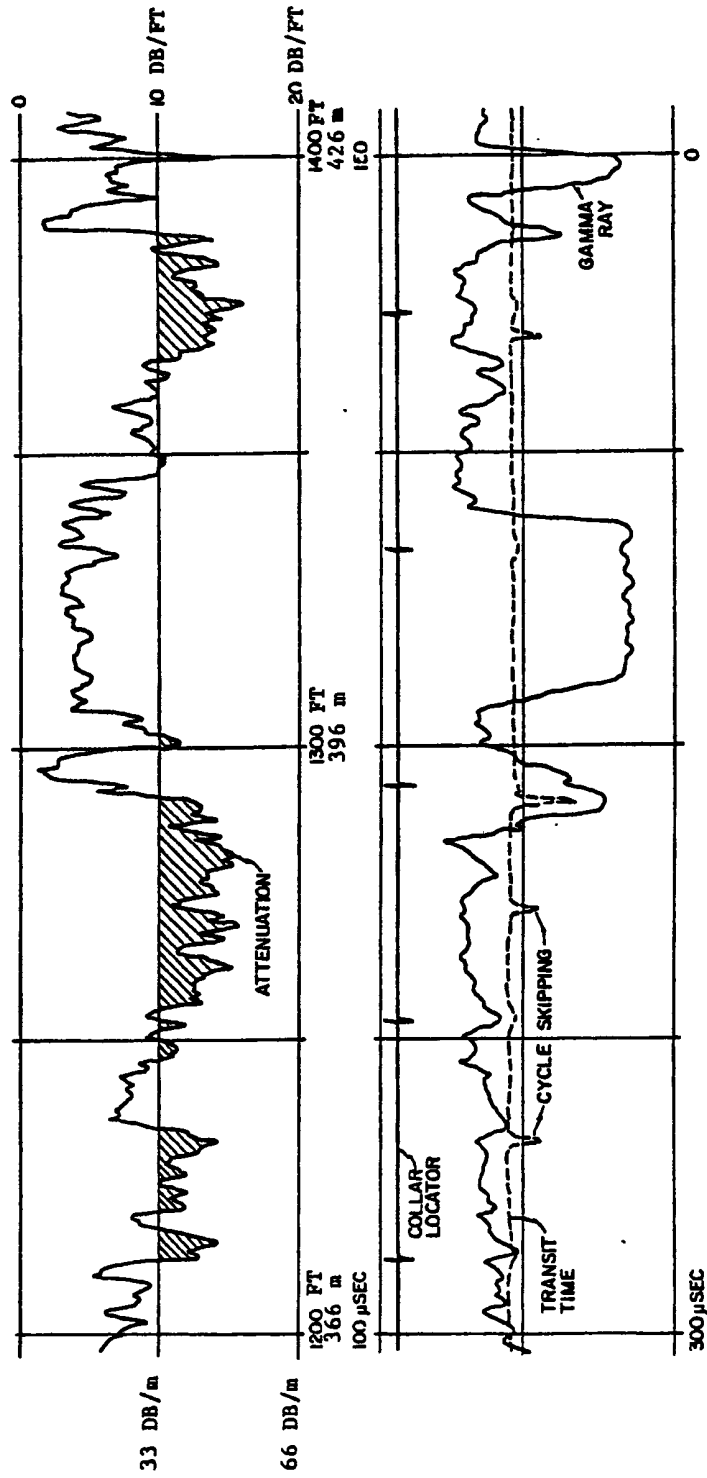


FIG. 5

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